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TECH

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PRINCIPLES OF PERFOR

by Lee Bower

When you were in high school and got your first car, the first performance modification was a free flowing exhaust system. Though it made more noise, there was definitely an increase in performance. Performance exhaust systems for personal watercraft are much more technical than a system that simply flows better. It must make power from low rpm all the way up to full throttle. Rather than just being a tube that flows high volume, a PWC exhaust has strategic bends and shapes that make horsepower where you need it.

TWO-STROKE 101

To understand what an exhaust does, let's look at a typical two-stroke motor's operation. First, an electric starter turns the crankshaft of the engine. In each cylinder, a rod is connected to a piston that slides up and down in the cylinder. One revolution of the crank equals one up and down movement or two strokes of the piston.

When the piston moves up while starting, it creates a vacuum in the crankcase area (the area under the piston and around the crankshaft). The vacuum sucks the mixture from the carburetor and through the intake reed or rotary valve into this area. What goes up must come down, including the piston. As the piston is pulled down, the pressure created (intake valve closed) pushes the mixture through transfer ports into the cylinder area above the piston.

As the crank turns, the piston compresses this mixture for ignition by a spark from the spark plug. The spark ignites the mixture causing an explosion that pushes the piston down turning the crankshaft. Now that the engine is started, this cycle will occur at about 1000 to 7500 revolutions per minute (rpm) depending on the carburetor's throttle valve position.

EXHAUST WAVES AND PLUGS

After the explosion forces the piston down, the burned gases (exhaust) exit the cylinder through the exhaust port into the exhaust system. When the piston is down, the exhaust port is open and exhaust is exiting at the same time a fresh mixture is entering the cylinder. In a tuned exhaust system, the exhaust creates a sonic wave in the system's expansion chamber (the big part of the pipe) that bounces and returns to the exhaust port essentially plugging the port so the fresh mixture doesn't escape.

The variables that control the timing of the sonic wave returning to plug the exhaust port are the angles and length of the head pipe, diffuser and convergent cones along with the expansion chamber's length and diameter. Since the wave is sonic and sonic means sound, temperature will also control the timing of the exhaust port plugging wave. Temperatures can be controlled by the location and amount of water that is injected into the expansion chamber (or head pipe) to cool the exhaust and changing the speed of the sonic wave.

Changing any one of these variables, also changes the powerband of the engine, for example a longer expansion chamber will allow the engine to produce more horsepower at higher rpms, sacrificing torque required for hard acceleration. Personal watercraft currently are not offered with transmissions, so designing a system that produces power throughout the entire powerband is not an easy task. Starting with design of the watercraft's stock exhaust system, aftermarket exhaust manufacturers experiment until they find a combination of angles, lengths, diameters and temperatures until a goal is reached. Hundreds if not thousands of hours along with hundreds of test samples are invested to develop a pipe that performs better than the stock version.

There is no right or wrong in system design, only different parameters and tradeoffs. Philosophies will vary with each company. Timing and the amount of plugging at different rpms is critical to high performance two-stroke engines. If the wave returns too soon, the spent gases will get trapped with the fresh mixture, whereas if the wave is too late, the fresh charge will escape.

One manufacturer may build a system that has strong low end torque sacrificing high rpms. On the opposite end of the spectrum, another manufacturer may design a system that allows the engine to rev at high rpms, but this type of system will reduce low end torque.

Ideally, an aftermarket exhaust system will enhance the power at all rpms. A couple years ago, Factory Pipe of Ukiah, CA, released a system that offered the best of both worlds with the help of their ECWI (Electronic Controlled Water Injection) feature. At low rpm, an electronic solenoid, shuts off water flow into the exhaust increasing low end torque. When a specified rpm is reached, water is then injected into the exhaust to produce top speed. Essentially, by changing the temperatures, the engine performs as if the pipe changes size. Several companies now offer similar electronic water control systems.

We've often heard the engine's cranking compression is the determining factor in the octane rating of the gasoline recommended for a particular engine. With the addition of an aftermarket exhaust system, those theories become myths. The increased plugging of the exhaust port will increase the engine's operating compression, resulting with an engine that may require gasolines with higher octanes.

These principles are easy with a single or twin cylinder engine. Twin-cylinder engines have the pistons firing 180 degrees out of phase with each other allowing a single pipe to work in unison with both cylinders. On three cylinder engines, the pistons are firing 120-degrees apart and usually have exhaust manifolds that have a different length wave path for each cylinder resulting in different

USTED

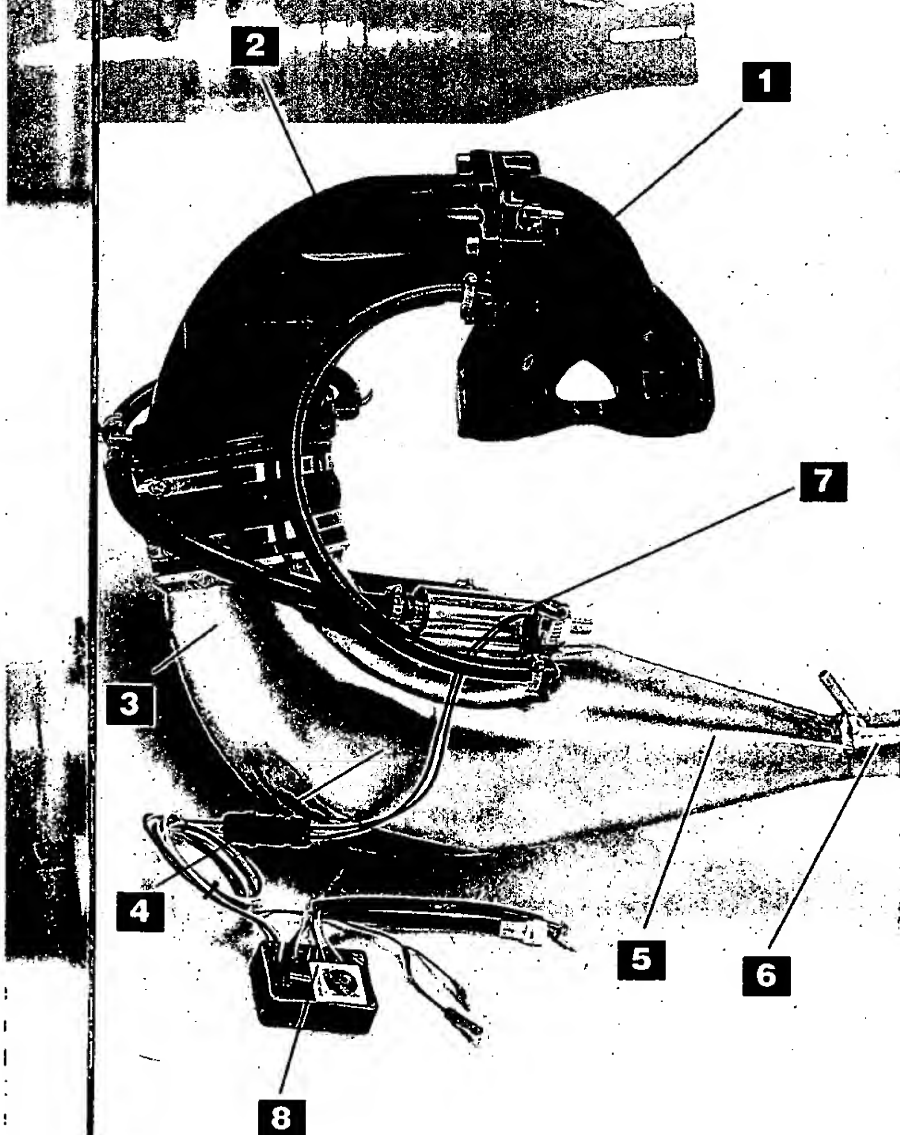
MANCE EXHAUST SYSTEMS

powerbands for each cylinder. Due to cost limitations three cylinder boats are typically equipped with a single pipe, however, as an aftermarket alternative, triple pipe systems offering huge gains are available at premium.

To reduce noise, PWC use a waterbox as a muffler. The waterbox also affects exhaust backpressure and the plugging effect. Cooling water sprayed into the exhaust fills up the waterbox to muffle the exhaust sounds.

Before purchasing an aftermarket exhaust system, call the different manufacturers to determine what other modifications are required or recommended and be prepared to follow them. Also, horsepower claims are hard to prove or disprove so be wary of claims that may seem unreasonable.

Similar to your old car from high school, the most horsepower gains can be from the installation of an aftermarket exhaust system. Check out the Exhaust Buyer's Guide in this issue for more information on the many systems currently available.



1.EXHAUST MANIFOLD-The exhaust manifold combines the spent gases from each of the exhaust ports of the cylinder.

2.HEADER PIPE-To keep engine and exhaust temperatures down, the header pipe has a water jacket around the shell of the exhaust. Exhaust temperature and sonic wave speed can be controlled by the location and the amount of water that is injected into the exhaust from the header pipe.

3.DIFFUSER CONE-The diffuser cone shapes the sonic wave as the exhaust is exiting. In addition, it shapes the return exhaust port-plugging wave to keep the fresh fuel and air mixture from escaping the combustion area of the cylinder.

4.MAIN EXPANSION CHAMBER BODY-The large part of the exhaust is one of the many key tuning variables of a performance exhaust system. Changing its length or diameter will change the rpm where the horsepower is produced.

5.CONVERGENT CONE-As the exhaust (and the sonic wave it produces) bounces off the convergent cone, it returns to plug the exhaust port. Similar to the diffuser cone, changing the length and angles will result in a different shape and frequency of the wave, again resulting in a change of the engine's powerband.

6.STINGER-This is where the exhaust exits the tuned part of the pipe before it enters the waterbox (muffler). The diameter of the stinger and the amount of water injected changes the amount of exhaust backpressure. A smaller stinger or a lot of water injected will typically increase top speed sacrificing low-end torque.

7.WATER FLOW SOLENOID-Using water pressure from the pump drive, the solenoid works like a valve to inject water into the pipe to change the temperature of the exhaust. By changing the temperature, the speed of the sonic wave changes essentially having the affect of changing the operating size of the pipe. In some systems, multiple injectors may be used to reinforce certain powerbands.

8.ELECTRONIC CONTROL MODULE-This module regulates the water flow solenoid based on rpm of the motor. Some modules can be programmed by switches to either open or close a solenoid at a given rpm to create the maximum horsepower throughout the full rpm range of the engine.